Exploring Energy - 3

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Geothermal Energy

by Sean McCutcheon

Right:
The inexhaustible flow of heat from within the Earth is the source of geothermal energy. The Earth is hot; the mantle is hotter than the crust, and the core hotter still. Most of our planet's billions of cubic kilometres are at, or above, the temperature at which, under normal conditions, rock melts.

Left
Measuring the temperature of the water spouting from a hole drilled at the site of the Mount Meager hot springs in British Columbia

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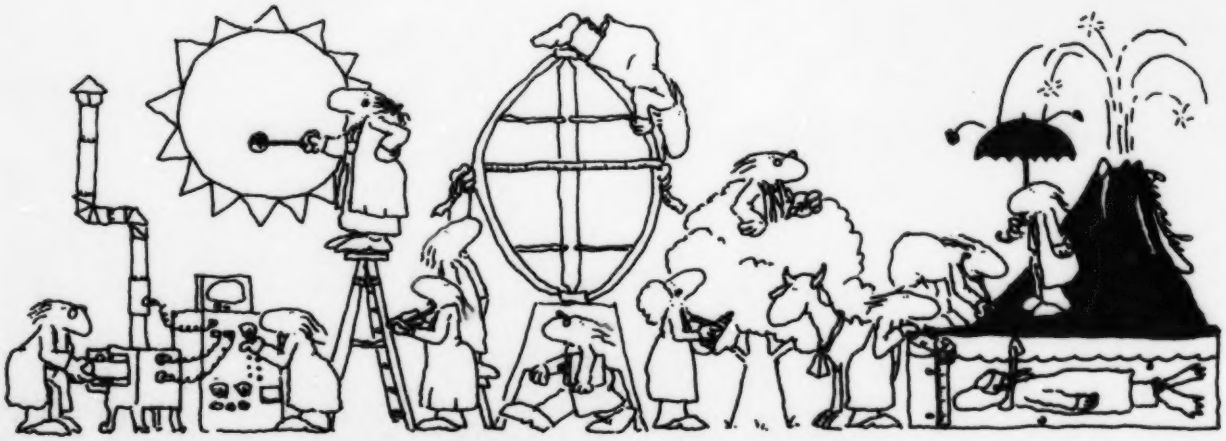
Foreword

Despite a global abundance of fossil fuel reserves it is clear that their exploitation is becoming ever more difficult and costly in many regions of the world. The shock of oil disruption in the early 1970's triggered a search for alternative energies that would either be renewable or inexhaustible and thus remove forever the spectre of depleting resources, shortages of fuel and the attendant social disruption. Canada has for some years been following a course of Research, Development and Demonstration of alternative energy forms and this booklet is intended to inform you on progress towards their utilization.

Geothermal energy is energy drawn from a massive reserve, the heat contained in the Earth's crust. The Canadian program lags behind that of other countries because of the extraordinary endowment of lower cost alternatives available to Canadians prior to the 1980's.

New sources of geothermal energy discovered through explorations, technological improvements in countries using geothermal energy and sharply increased costs of Canadian fossil fuels are factors which indicate that the next 20 years will see increasing need for contributions of geothermal energy to electricity generation and space heating.



Contents

The continuing (but declining) availability of hydro sites and of fossil fuels will together constrain geothermal applications to modest growth rates. This will allow time for the development of more efficient equipment for exploiting geothermal heat and improved disposal techniques in locations where waste water is an environmental problem.

The current exploration for geothermal resources has produced a general map of the resource, published here. The costly process of translating resource to reserve data will take place as demonstrations such as those described in the following pages are commissioned and experience is gained. It is our hope that the 1980's will continue to lay the foundation for a geothermal future in Canada.

Energy Research and Development Program
National Research Council Canada

Coal and Alternative Energy Branch
Energy, Mines and Resources Canada

Canadian Perspective

There is a highway running north from Vancouver. It skirts a fiord, then winds through majestic mountains to end, after a hundred or so kilometres, in an isolated valley known as Pemberton Meadows. From here a logging road runs northwest and, after about 40 kilometres, reaches our destination — the steaming pools of a cluster of hot springs. The water which wells up here from underground can scald, at places its temperature exceeds 50°C. Even after the heaviest snow-falls, the patch of gravel and boulders amidst which these springs rise is always warm and bare.

The hot springs lie on the flanks of a glacier-clad mountain complex — four of its craggy peaks top 2 750 m. This is Mount Meager. It stands at one end of the chain of mountains to which Mount St. Helens also belongs, and like its celebrated neighbor, Mount Meager is a volcano.

Here, during past millennia, molten rock rising through vents from deep underground built up enormous pressure and erupted. The last of the many times this happened was some 2500 years ago, when the mountain exploded so violently that ash from it can be found today spread across the Rockies and the western edge of the Prairies. Mount Meager is now dormant, but its rocky roots, the source of the springs' spectacular flow of energy, are clearly still hot.

Geologists and drill crews have been exploring Mount Meager's roots, probing an underground reservoir of porous rock filled with water and steam at temperatures above 200°C. They may have found a natural pressure cooker big enough, hot enough and with high enough pressure to power a generating station. Here, for the first time in Canada electricity may be produced from geothermal energy.

Geothermal energy is energy in the form of heat. From the Earth's hot interior, up through the rocks beneath our feet, heat is always rising. This heat flows

Mount St. Helens, Sunday morning, May 18, 1980

at every point on the surface of the Earth, but usually in small quantities. Only where nature has concentrated these flows of energy can we usefully tap them. We can, for instance, generate electricity from the pockets of steam, or hot water, occasionally found in volcanic rocks. We can heat buildings, and warm water for domestic and industrial use, by pumping up the Earth-warmed waters found in many places within sedimentary rocks. Moreover, any energy we draw off will eventually be replenished by the unfailing flow of heat to the surface of the Earth. This does not happen instantly, however; it probably takes much longer to reheat a geothermal reservoir than it takes us to cool one. However, estimates of the practical lifetimes of geothermal reservoirs remain uncertain, for no reservoir has yet been drained of its heat. Some geothermal energy projects have released chemical pollutants to the environment but safeguards (such as the reinjection of water back into the ground) have been developed. Geothermal energy, in short, is versatile, inexhaustible in the long run, and relatively clean.

Geothermal energy was commercially exploited for the first time in Canada at Banff, Alberta. In the winter of 1883 Frank McCabe and his mates, part of the army of men pushing the Canadian Pacific Railroad westward, spotted what looked like smoke rising from the side of a valley. They investigated and found steam smelling of sulphur and coming from a hole in the ground. When they dropped a burning branch into the hole, there appeared below them a large circular cavern, and on its floor, a pool of steaming hot water. The men lopped the branches off a spruce tree to make a rough ladder, climbed down, and happily soaked themselves in the natural bath. Soon after this discovery, the Banff hot springs were being enjoyed by many; a hotel was built, and then a town, and this became the site of the country's first national park.

The remainder of Canada's geothermal history is quickly sketched: other hot springs in the volcanic rocks of the West were developed for recreation; Moose Jaw built a swimming pool which continued to be warmed by water pumped up from sedimentary rocks until the wooden well casing rotted; and today the town of Whitehorse keeps its pipes from freezing by mixing water from a hot spring with the municipal water supply.

Is it practical for use in Canada? Aside from recreational use at hot spring resorts like Banff, geothermal energy is not yet put to work in this country. But any report on a young and dynamic field is bound soon to be out of date. The first international conference on geothermal energy was held in 1970, and the handful of people who have been taking stock of Canada's geothermal resources began their work even more recently. They have been encouraged by many promising discoveries, and their mood is now one of optimism. Geothermal energy as the following pages report, is likely to make useful contributions to Canada's energy supply.

The hot springs at Banff, discovered by railroad workers in 1883, became the first geothermal resource to be commercially exploited in Canada.

Global Perspective

Everywhere the history of geothermal exploitation begins in a similar way: with the use of natural hot water for baths. Romans, Greeks, Turks, and Japanese — people from every culture have thronged to hot springs seeking pleasure and health, convinced that the steaming mineral water will cure their ailments.

The next important step in the application of geothermal energy, the conversion of the Earth's heat to electric power, was first taken in Italy at the beginning of this century. At Larderello, near Pisa, are found fumaroles, or steam springs, natural holes in the ground from which steam issues. Dante's visit to the area may have inspired some of the smoking scenes of hell in his *Inferno*. In 1904, at a factory in which boric acid, a disinfectant, was being made from the hot mineral waters, Prince Piero Ginori Conti switched on five light bulbs which were powered by electricity generated by geothermal steam. Over the years, the amount of power generated at this site has grown, and now more than 400 MW are fed into Italy's grid.

A similar geothermal field occurs in the United States, north of San Francisco. William Elliot was hunting grizzly bears one spring day in 1847 when he stumbled upon a canyon that smelled of sulphur, and that had steam spouting from its steep walls. He was awestruck; he told his friends afterwards he thought he had found the gates of hell. This steam was first tapped for electricity in 1960, and today the largest geothermal plant in the world, The Geysers, converts it into almost 1000 MW of power.

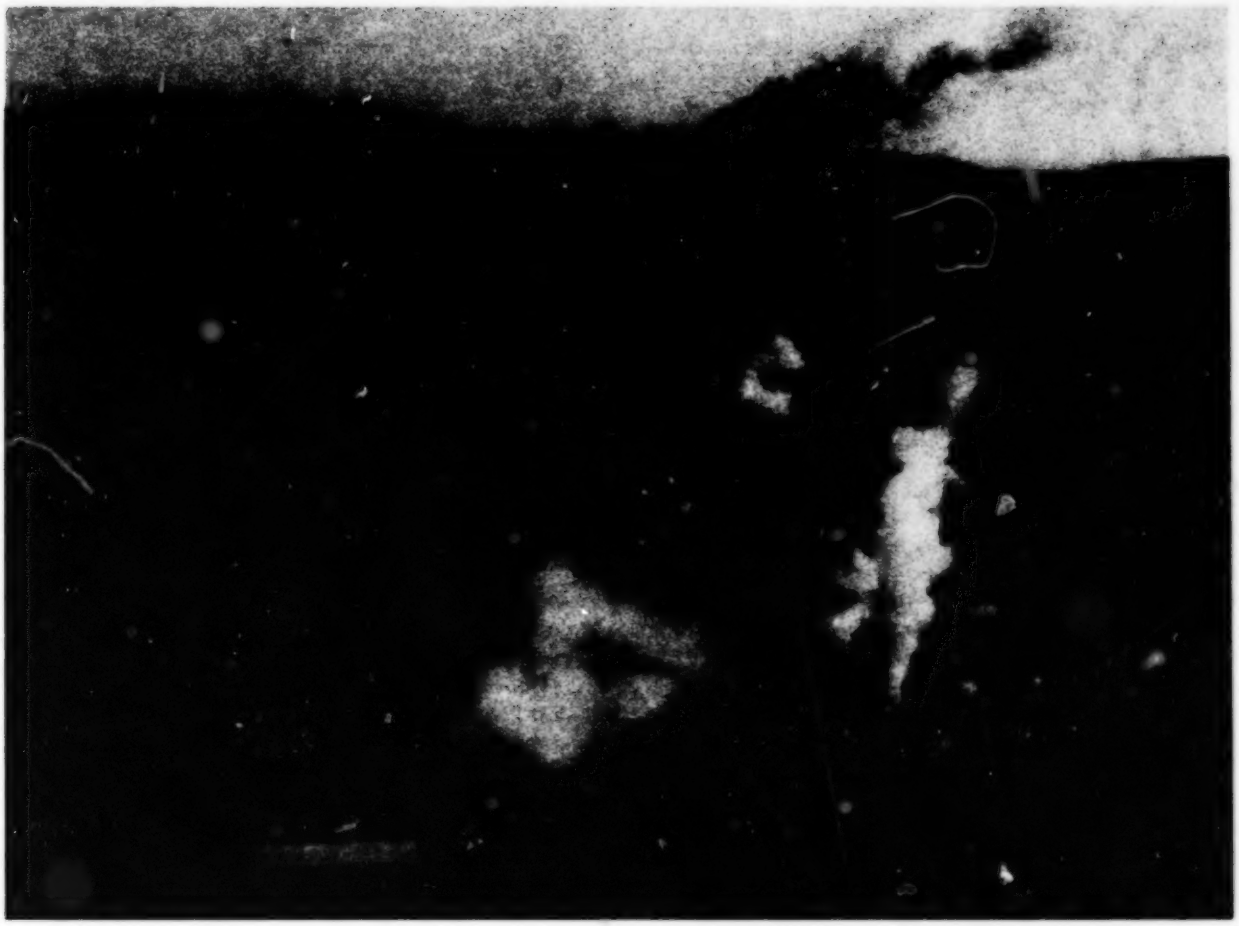
Three geothermal fields have been developed on the North Island of New Zealand, which together produce around 350 MW. During the past two decades China, El Salvador, Iceland, Japan, Mexico,and a number of other nations have built relatively small geothermal power plants; so that today a world total of approximately 3 000 MW of geothermal power is being generated; and a good deal of expansion is planned or in progress.

Iceland was the first country to take the step of using warm water from the earth for heating. More than 40 wells have been drilled since 1930 in and around the capital, Reykjavik. From these wells heat in the form of warm water is piped to most buildings in the city for use in washing, bathing and space heating. Reykjavik boasts that, as it burns no fossil fuels, its air is smoke free, and its citizens delight in the seeming contradiction of their city's name — "Reykjavik" means "smoky bay". It was steaming hot springs, not fires which gave the city its name. In fact, most communities on this small mid-Atlantic island have clean, clear air for most are geothermally heated.

The source of heat under Iceland is hot volcanic rock. In France, which also has geothermal heating in its capital city, the heat source is sedimentary rock. Warm water is held in the bowl-shaped sedimentary formation, hundreds of kilometres in diameter, known as the Paris Basin. At Melun, a suburb of Paris, bore holes drilled in 1970 now bring warm water, at an average temperature of 80°C to the surface. Its heat, extracted by a heat exchanger, helps keep a large block of apartments warm. This project has spawned many others and when present plans come to fruition, 500 000 apartments in France will be geothermally heated.

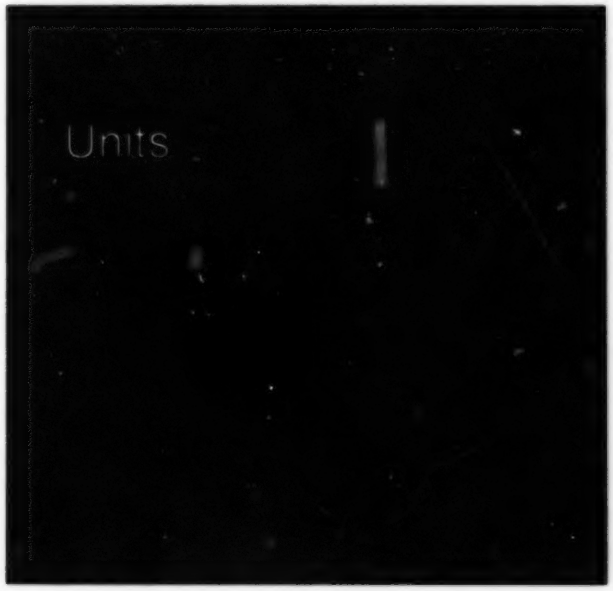
The Russians grow millions of tons of vegetables in greenhouses which are heated by warm water from sedimentary rocks. Much of Hungary's paprika also grows under glass, warmed by heat from sedimentary rocks. In Iceland, the potato is about the only domestic plant to flourish outdoors; but in geothermally heated greenhouses, plants as diverse as garden flowers and bananas are grown.

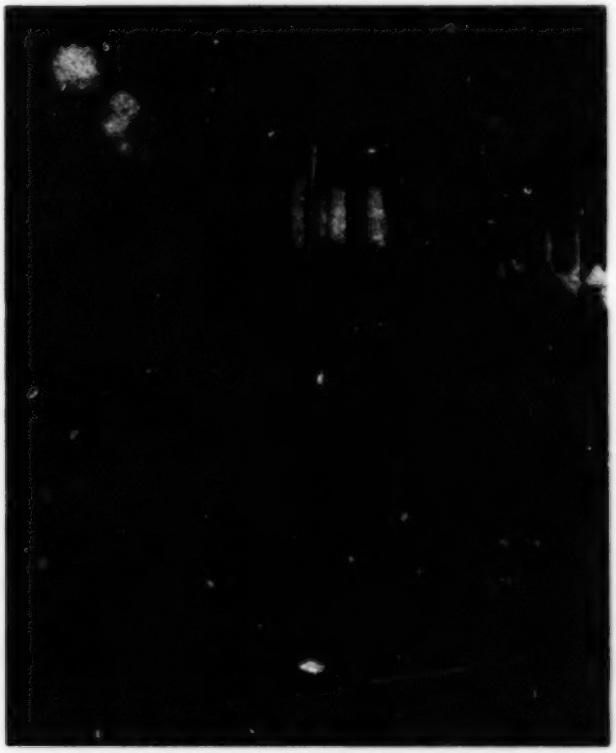
Still other ways of putting the heat of the Earth to work have been devised. Japan has some exotic examples, including geothermally heated fish hatcheries, eel ponds, alligator nurseries, lily gardens, and breweries. Yet, the most important applications, after the early phase of building baths, remain the generation of electrical power and the heating of buildings and greenhouses.



Plumes of steam, tapped from underground reservoirs, roar through valves at The Geysers, California. In the turbine houses (top and bottom left), more than 500,000 kW of electrical power is generated, enough for a city of half a million people.

This poultry yard, the northernmost in Russia, is geothermally heated.





Earth's Heat

Forty kilometres north of Reykjavik, superheated water belches from a steep rock face and forms a boiling river. This is yet another instance of a worldwide class of phenomena that includes hot springs, natural cauldrons of boiling mud, intermittent geysers of steam and boiling water, and volcanoes that have many times buried large areas under red-hot lava. From such evidence, it is reasonable to assume that, in the words of English physicist and chemist Robert Boyle, written 300 years ago, "in these yet impenetrated Bowels of the Earth, there are great store-houses of either actual Fires, or places considerably Hot. . ." Most of our forefathers, in fact, believed that beneath their feet lay Hell, a region of fire in which sinners were punished for all eternity.

Geophysicists have confirmed that the Earth is hot, both directly, by measuring temperatures within its crust, and indirectly, by finding ways to estimate a good deal about the deep, inaccessible bulk of our globe.

If the Earth were apple-sized, our deepest mines and drill holes would barely prick its skin. Measurements within the uppermost 10 km of this skin show that temperature rises steadily with depth, at an average rate of about 25 Celsius degrees for every kilometre.

The crust, on the surface of which we live, is the thinnest of the spherical shells, nested one within another, which make up the Earth. It is thinner under oceans, thicker under mountains; rarely does it exceed a thickness of 50 km. The base of the crust is at an average of about 600°C.

Below lies the mantle, 2 900 m thick. Only the top of the mantle is rigid. At a depth of 100 km beneath the Earth's surface, barely into the uppermost layer of the mantle, temperatures have risen to the point at which rocks, at ordinary pressures, melt. Below this depth temperature continues to rise, though at a slower rate than in the crust, and rocks behave in a manner between that of solid and of liquid: they creep, like glass or pitch. We can picture a thick, simmering soup — seen in extremely slow motion — with heated material rising from the bottom of the mantle, crossing beneath the crust, and then falling again, to form the gigantic, lazy whorls known as convection currents.

Below the mantle lies the iron-nickel core. Its boundary with the mantle may be at 3 700°C; its, and the Earth's, centre may be at over 4 000°C. The outer core is molten. The inner core is squeezed by such immense pressure that it remains, mysteriously, solid.

What is the source of the Earth's heat? Cosmic collisions and nuclear disintegrations, say the geophysicists.

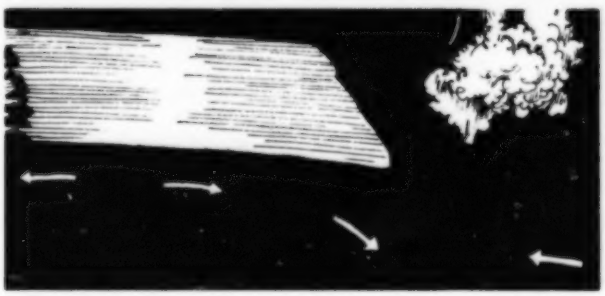
Earth and its neighbors, they theorize, were born from a vast rotating cloud of hot gas and dust, relics of explosions of distant supernovae. This material coalesced at its centre to form the Sun, around which, as particles collided and clumped, the planets grew. These collisions generated considerable heat, so that the Earth was hot when it was new, almost five thousand million years ago.

Radioactivity then caused the internal temperatures to rise. Embedded in the rocks are powerful internal "heaters" — radioactive elements, predominantly long-lived isotopes of potassium, thorium and uranium, which spontaneously decay and convert their nuclear energy to heat. When the temperatures rose to the melting point of iron, vast drops of molten metal fell to the core, releasing gravitational energy in the form of yet more heat. The heavy elements fell, the light ones rose; and the process of zoning the Earth also heated it. Most of the radioactive elements rose to the crust, where they are now concentrated in the light granites, and where they act as the principal source of the heat flowing out of the continents. It will be millions of years before a significant fraction of these radioactive elements disintegrate; from a human point of view, the flow of heat from within the Earth is inexhaustible.

It is also enormous. The amount of heat energy reaching Earth's surface in a year exceeds by a factor of ten all the energy now used by man in a year. This total is spread over Earth's entire surface, however, so that the average amount of heat flowing through a unit area is small — about one ten-thousandth, in fact, of the average solar energy falling on the same unit area. This flow of heat is so diffuse that it would take a year to melt a layer of ice only a few millimetres thick.

The *average* flow of heat at the surface of the Earth, in other words, is far too weak to harvest. Nonetheless, internal heat drives geological mechanisms that are

Descending the glacier-coated sides of a volcanic crater (in Russia) to explore a boiling lake at its bottom.



The existence of molten rock near the Earth's surface, and hence of geothermal reservoirs, can be explained by the motion of the plates into which the Earth's uppermost layer is divided. Three plates are shown here. Where two of them diverge, molten rock wells up from below to fill the gap. Where two plates collide, rocks are melted by friction, and volcanoes erupt.

continually reshaping our planet, raising mountains, making earthquakes — and creating, in the process, *concentrated* pockets of geothermal energy. It is these concentrated pockets that can be practical sources of energy for us.

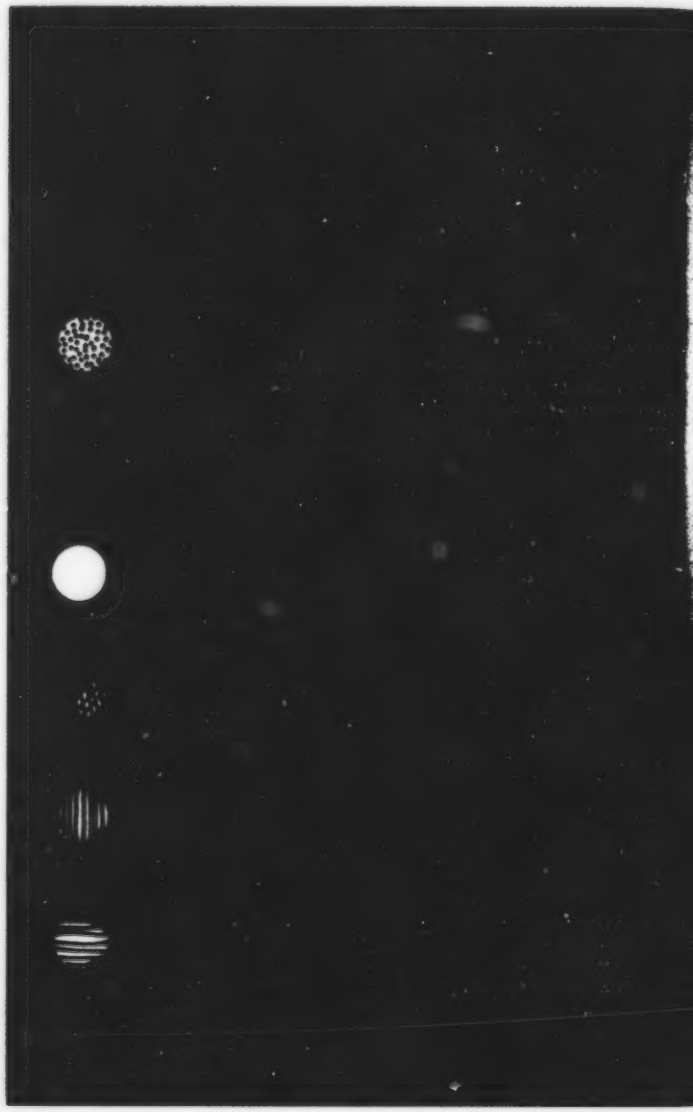
Nothing seems as immobile as bedrock. That it moves, that the Earth's rigid outer shell (100-150 km thick; composed of crust and the outermost portion of the mantle) is broken into several dozen huge plates, floating like rafts, and that heat-driven currents in the plastic interior drive the plates in a ponderous, bumping dance — these were new and startling ideas a generation ago. Yet, because they explain so much so tersely, almost every geophysicist and geologist now holds them to be at least approximately true.

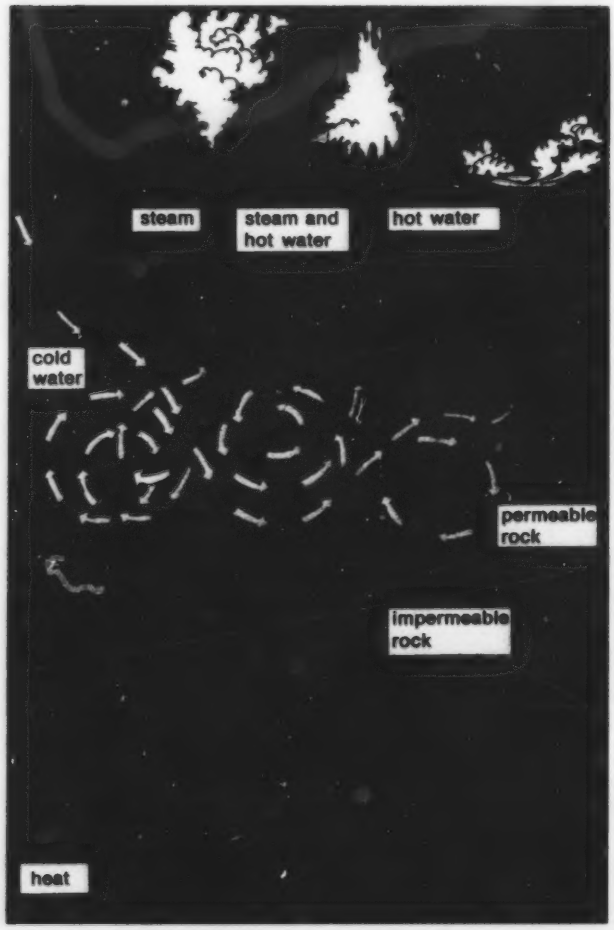
Plates collide, plates diverge. An oceanic plate, for example, plunges beneath a continental plate. The jerks and shocks of its descent are what we call earthquakes; the eruption of molten rock, heated by its downward slide, we call volcanoes; the crumpled, folded rocks it forces into the air; we call mountains. Two oceanic plates pull apart at a rate of a few centimetres per year, and the resulting fissure in the crust is continually filled by upwelling magma — molten mantle rock.

Intense volcanic activity delineates the boundaries of the Earth's plates, and in these narrow volcanic zones about 1 per cent of all the Earth's heat flow is concentrated. The inhabitants of these zones enjoy a somewhat mixed blessing: the risk of eruption and earthquake but also the opportunity to tap geothermal energy. Larderello in Italy, The Geysers in the United States, the New Zealand fields — all the world's geothermal power projects are located in such zones.

Geothermal Resources

For each volcano there are probably hundreds of areas in which molten rock has pushed upwards to within a few kilometres of the surface of the Earth. It may take millions of years for such underground magma chambers to cool, for the solid rock that surrounds them also insulates them; rock is a very poor conductor of heat. What stores the heat in pockets, and thus turns a geological accident into a geothermal resource, is water. In tapping the Earth's heat, one is not mining rock, but water, and thus a convenient way to classify different kinds of geothermal resources is by "hotness" and "wetness".





1. Steam Reservoirs

Water permeating fissures and cracks in rocks which are heated to high temperatures (ranging around 235°C), may, depending on the pressure, turn to steam. If it does, and if this underground reservoir is sealed above by a lid of impermeable rock, it will become a kind of pressure cooker. The water will be pushed down by the pressure of the steam, so that, if a hole is drilled through the lid, dry steam — under pressure and superheated — will escape. This dry steam is an excellent medium for driving steam turbines and, in turn, electrical generators. Reservoirs of dry steam, though, are rare; only four are now exploited.

Geothermal reservoirs form when rain water which flows underground into a permeable layer of rock is heated by hot, molten rocks some distance below. The resulting hot water and steam escapes up through fissures in a layer of impermeable rock and is vented, at the surface, as fumaroles (steam springs), geysers (fountains of steam and water) and hot springs.

Mount St. Helens

2. Hot-Water Reservoirs

Water heated to high temperatures underground will not necessarily turn to steam if confined under high pressure. However once this superheated water is exposed to air pressure, it will "flash", with a blast of noise. Less than a third of the water will actually vaporise. The majority will stay as a boiling hot liquid. This is a wet-steam reservoir, the kind that is tapped for electricity at most of the world's geothermal power plants. (Interestingly enough, lowering the pressure of a hot-water reservoir in New Zealand changed part of it into a dry-steam field.)

3. Warm-Water Reservoirs

When the temperature lies between 60°C and 140°C, as it does in the warm water near and under Reykjavik, electricity cannot be generated — not, at any rate, by means of conventional technology. But like an open pot used to warm rather than boil water, this kind of reservoir is tapped for heating.

4. Hot Dry Rocks

Concentrations of heat close to the surface are common not only in volcanic regions. Elsewhere, they may be due to, among other causes, locally high levels of radioactivity. But if the heated rocks are dry — either because they are solid, and thus hold no water, or because they have no underground supply of water — they are about as useful as a hot but empty kettle. To tap their heat, water must somehow be added, and to do this requires complex, and as yet imperfectly developed, technology.

5. Sedimentary Reservoirs

In volcanic zones, heat flows are usually concentrated. In sedimentary basins, heat from diffuse flows is often accumulated and stored in the form of warm water, creating an entirely different kind of geothermal resource.

Sand and similar debris, settling on the floors of ancient seas, form sandstone and other sedimentary rocks. The deposits pile up, layer upon layer, and if undisturbed, can form rocky basins that stretch hundreds of kilometres. The empty spaces between grains of sandstone occupy up to one-fifth its volume, and thus water can percolate through it. This water in a sandstone or similar sedimentary basin will be warmed by the flow of the Earth's heat from below. For example, the average temperature at a depth of 3 km is 75°C. If the water-bearing layer were at this depth, and if it were also covered by an insulating blanket of impermeable rock, then it would slowly collect heat until all its water had reached this temperature. It is worth noting that sedimentary heat reservoirs, because they are stocked by the diffuse, average flow of heat from the Earth's interior, are replenished more slowly than steam or hot water reservoirs.

In France, Hungary, the Soviet Union, and other countries, warm water from sedimentary rocks is heating buildings and greenhouses. This kind of geothermal resource lies below much of the world's habitable land.

Exploration

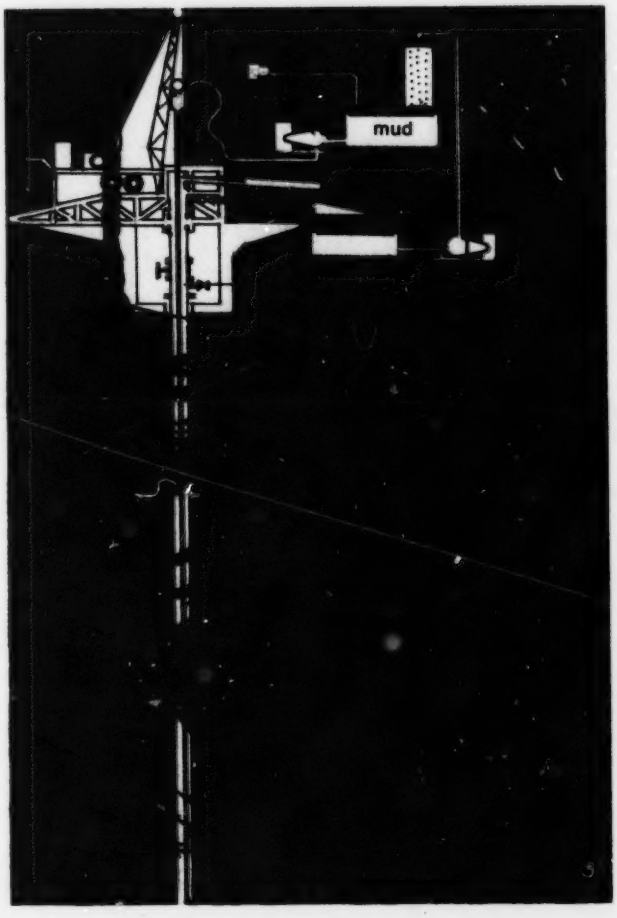
To get energy from a geothermal reservoir you first must find one.

The sedimentary basins are large, obvious, and usually already well-mapped as a result of explorations for oil and gas. The search for warm-water reservoirs in such basins begins with a study of geological maps and past drilling records; but to get the specific information that engineers designing a geothermal heating system need — that is, to measure temperatures, pressures, salinity and the like — you must drill again.

Finding steam and hot-water reservoirs in geologically complex volcanic zones is more difficult. Dry-steam fields like those of Larderello and The Geysers declared their presence clearly with spectacular fumaroles, geysers and hot springs. But to discover such an obvious geothermal resource now is as unlikely as stumbling upon a new oilfield marked by oil seeps on the ground.

A systematic search for geothermal steam usually begins with a survey of hot springs. These are so numerous in volcanic regions, that their mere presence is not a clear indicator of what may lie hidden below. Analysis of the minerals dissolved in their water, however — of the ratio of sodium to potassium, for instance — tells geochemists something about temperatures in the underground rocks from which these minerals came. To probe the structure of underground rocks and fluids, geophysicists send seismic shock waves and electric currents through the Earth. Guided by such factors as porous, water-filled rock offering less resistance to current flow than solid rock, they are able to interpret their observations for useful clues. But, at best, surface exploration techniques yield only clues. To obtain facts, drilling is required.

Drilling for heat is at least as complicated, costly and hazardous as drilling for minerals. Oil-drilling rigs are used on geothermal projects, and their crews of roughnecks have much the same kind of work drilling for steam or hot water as for oil. They bolt a section of drill pipe, suspended from a derrick, to the sections already in the ground and then start a powerful diesel engine. It turns all the pipe, and at the bottom of the hole the drill bit bites and bores its way down through rock.



At work on a drill rig, roughnecks add another length of pipe to a drill string. In the background, a typical rotary drill rig is shown schematically.

The speed at which the hole deepens depends on the nature of this rock. Volcanic rock is often much harder than the sedimentary rock in which oil and the warm water used for geothermal heating are found. It may take up to 45 days to drill down 1 km into volcanic rock, and another ten days to test the hole and line it with steel casing. As the hole deepens, progress slows and costs climb, so much so that drilling much deeper than 2 km is now impractical.

The very heat being sought makes geothermal drilling in volcanic rock slow and tricky. Water or mud is circulated down the hole to cool the drill bit and clear away rock chips. But as a hot spot is approached, this fluid can come up boiling and hence requires special handling. Also, to protect the crew from the scalding blowout that might occur if the drill suddenly pierced a highly pressurized reservoir of steam and superheated water, giant rubber rams must always be ready to automatically clamp the drill stem and seal the hole.

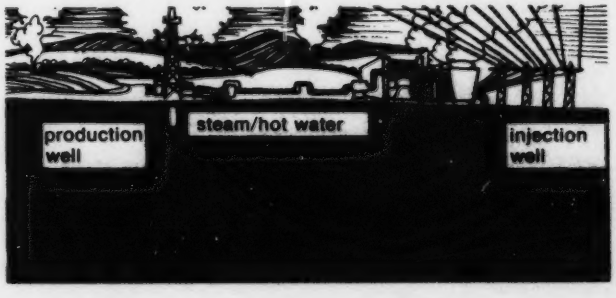
Electrical Generation

Once a reservoir is located, geologists and engineers must map it in great detail, to decide if factors such as size, pressure and temperatures are such as to warrant exploitation. If they are adequate, then the production wells are drilled and connected by a maze of pipes to turbine-generators. Finally the valves are opened and the power is turned on.

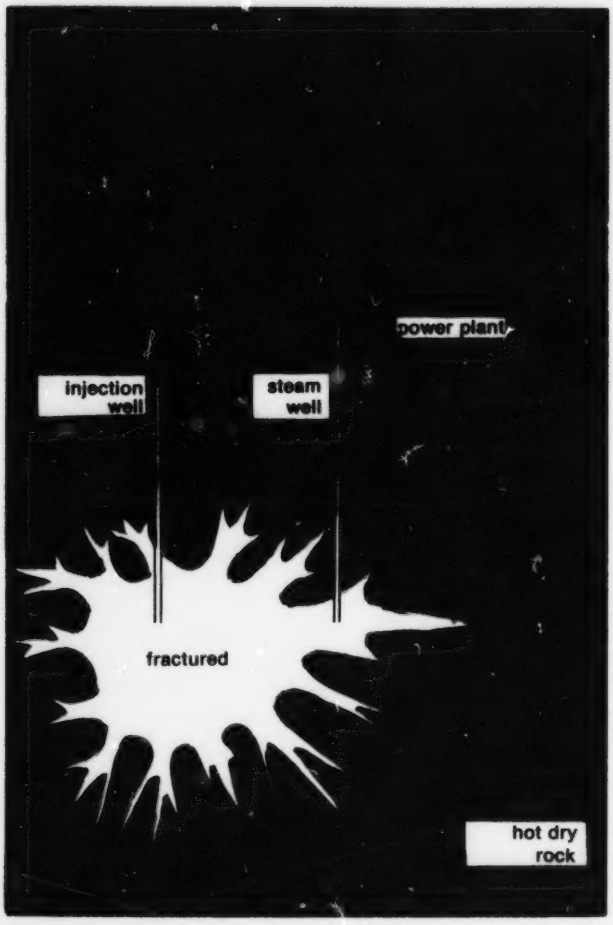
The function of most of the hardware visible at a geothermal power plant is straightforward. At the wellhead, there are silencers (steam discharging can make a deafening blast), and separators, which separate steam from hot water. There is a lot of heavy-duty plumbing around, gathering steam from clusters of wells into a main line. There is a building housing turbines and generators. The turbine blades are rotated by expanding steam, while the generators convert the energy of the turning turbine shafts into electrical energy. Also at each plant there are characteristically curved cooling towers, in which used steam is released to the air, and sometimes there are reinjection wells, through which waste hot water is returned to the ground.

About the only technical problem peculiar to geothermal power plants arises from the nature of hot brines. The hotter the underground water, the more salts it can dissolve from the rocks through which it passes. When the water cools above ground, these salts precipitate to form thick deposits, fouling bore holes, pipes and turbine blades. The brines are corrosive as well; thus geothermal plumbing must be made of high quality, corrosion-resistant metals.

Curiously, this clogging may both create and end a geothermal reservoir. When minerals dissolved at depth spontaneously precipitate out and plug the pores in cooler rocks near the earth's surface,



From a production well drilled into an underground reservoir steam is piped to a power plant where it drives turbines and thus generates electricity. The hot waste water is pumped back into the ground.



The enormous energy contained by hot, dry rocks near the Earth's surface can be extracted by forcing water down an injection well to fracture the rocks, and by drawing steam or heated water up from the fractured zone to drive an electrical generator. Today, this experimental technology is inefficient and expensive.

they may thereby put the lid on what becomes an underground cooker. But the same process, after 15 or more years, can block the pathways taken by hot water to reach the bottom of a producing well. If the reservoir is to continue producing power, the choked well must be replaced by drilling another.

A geothermal plant provides what is called base-load power. The amount of power drawn from an electric grid varies. It usually peaks on dark, cold winter evenings, when almost everyone has plugged in some appliance. The output of a geothermal power plant cannot vary enough to match such fluctuations in demand; it remains constant, contributing power which helps meet the minimum load on a grid.

Heat is converted to electricity in a geothermal power plant, just as it is in a coal-fired or nuclear power station. But the steam raised in the Earth's boilers is lower in temperature and pressure than that raised in other power plants; geothermal electrical generation, consequently, is relatively inefficient. About 35 per cent of the heat energy in coal or oil-fired and nuclear power stations becomes useful electrical energy; in contrast, only about 10 per cent of the heat energy drawn from underground can become electricity. Efficiency is even lower than this in wet-steam fields, where a good deal of heat energy is in the form of hot water and is wasted because conventional technology cannot convert it into electricity.

The Future

Geothermal technology is standard technology, borrowed and adapted from other fields from oil drilling, steam plumbing, and power generation. What new developments are likely?

Improvements in heat extraction technology, such as the use of fluids that boil at temperatures lower than water — for example, freon — would make it possible to generate electricity from hot water now wasted. More significantly, improvements in drilling could make accessible many more resources.

At Los Alamos Scientific Laboratories in New Mexico researchers are investigating techniques for winning energy from hot dry rocks. They fracture such rocks with high-pressure water at the bottom of deep bore holes. Then they circulate water through the cracks they have made to the bottom of a second, nearby bore hole up which hot water rises to drive a 5 MW electrical generator. If such technology is successful, it could open up a widespread energy resource; but its full development will take until at least the turn of the century.

Warm water, heated by the gradual flow of heat through the Earth, gathers in layers of sedimentary rock. This water can be pumped to the surface, passed through a heat exchanger and then pumped back underground. The heat so gathered is at ideal temperatures (60-90°C) for heating apartments, swimming pools, greenhouses, domestic hot water and some industrial processes.

Heating

The technology for getting useful heat from sedimentary basins is simple and efficient. First, the basins are easy to find because they are large, geologically regular, and well understood. The techniques for exploiting them involve pumping warm water up a production well, running it through a heat exchanger, upgrading its energy content, if necessary, with a heat pump and pumping the cooled water back down a second well into the water-bearing strata. Equally standard from a technical point of view are methods of circulating the heat gathered by the heat exchanger, whether through apartments, offices and greenhouses, or for industrial purposes — the drying of food, for example.

In the suburbs of Paris, where the process is in use, pairs of wells have been drilled from a common point in the shape of an inverted "V", so that, with pumps and heat exchangers, they occupy no more land than a tennis court. Such a pair of wells supply enough heat to keep 1 700 apartments comfortably warm on all but the very coldest days, when supplementary electric heaters must be turned on. In Canada's colder climate, a similar installation, tapping water at 70°C at a depth of 1 750 m — not uncommon under the Prairies — could heat 1000 apartments, or 250 houses. Since the water of sedimentary basins is only warm, it is generally easy to handle. It can be very salty, but it is not extremely corrosive; and since it does not vaporise, none of the safety devices used with high-pressure steam are required.

This mode of tapping the Earth's heat makes sense, for low temperature (less than 100°C) energy sources are well suited for applications, such as heating space and water, that require low temperature heat. To use a high-grade source of energy such as oil or gas for these tasks may be convenient, but it is wasteful. Oil, for instance, should be saved for fuelling vehicles, rather than burned for heating homes, wherever the latter can be done with the Earth's heat.

Efficiency

Costs

Environmental

In the process of harnessing the energy of hot underground brines, dissolved gases and salts — carbon dioxide, hydrogen sulphide, compounds of chlorine, sulphur, mercury, arsenic and other toxic substances — can be released. Consider hydrogen sulphide. Its odour, redolent of rotten eggs, is characteristic of natural hot springs. A handful of people have died after inhaling hydrogen sulphide from fumaroles, for it can be lethal if highly concentrated. However, to control or eliminate the release of this and other noxious gases to the air is not technically difficult.

As well as polluting the atmosphere, geothermal plants can pollute water. At most operating fields, heavy flows of warm, salty fluids (they vary widely in chemical content; some contain toxic substances) must be discarded — tens of thousands of litres per minute. The best and cleanest procedure is to reinject waste water into the rock from which it came.

The most troublesome geothermal pollutant is probably heat. If you compare the environmental impact of two generating stations of the same power output, one burning fossil fuel, the other using geothermal steam, you would find that the fossil fuel plant produces much more atmospheric pollutants, while the geothermal plant releases much more waste heat. This heat could cause local climate changes, and thus interfere detrimentally with the lives of animals and plants. It can be simply controlled, however, by disposing of warm waste waters down an injection well. As well as limiting pollution by heat and chemicals, drilling such wells also prevents the slumping which can occur when large amounts of water are removed from an underground reservoir.

Living beside a geothermal power plant could be like living near a thundering waterfall; when steam blows freely into the atmosphere, as it must sometimes during maintenance, it makes an almost literally deafening roar. But very few people have geothermal generating stations as neighbors.

Geothermal fields usually occur in remote regions which are often of great natural beauty; the Mount Meager hot springs, to cite an example in Canada, are set amidst wild, forested mountains. Building and operating a geothermal power plant here, with its heavy equipment, service roads, and wells, will convert what was once an inaccessible beauty spot into an industrial site. No matter how much care is taken, this will spoil the site for some. (It is only fair to note, however, that the beauty of the Meager hot springs has already been tarnished by loggers who have cut down the trees in the area, leaving the forest floor littered with waste wood.)

All in all, the environmental costs of using geothermal energy, compared to those of other energy resources, (coal and strip mining; hydroelectricity and flooding; nuclear power and radioactive wastes) are relatively small.

Economic

Geothermal energy is never free, but in some places it may be cheaper than any alternative sources of power.

The price of energy changes as we learn more about our resources, as we develop new technology, and as governments and people act. Since no two geothermal reservoirs are identical, and since not very many have yet been exploited, the price of geothermal energy is especially difficult to fix. Nonetheless, we can be sure that as oil and other non-renewable sources of energy grow more scarce and more expensive, inexhaustible sources such as the Earth's heat will grow increasingly attractive.

Right: *A road passes under insulated steam lines at the world's most powerful geothermal power plant, The Geysers.*

Left: *Twin tower silencers, such as these in New Zealand, reduce the deafening noise of steam escaping in a geothermal field. (The machinery in the foreground is a separator.)*

Geothermal Heating

Most of the cost of tapping a geothermal reservoir is in exploration and drilling, and this has to be paid before anyone knows for certain that energy will be produced. Drilling is not cheap. A typical cost of a pair of wells bored into a sedimentary basin is more than a million dollars. Relative to this sum, the cost of constructing and maintaining a heating system to distribute warm water from these wells is small.

Obviously it would never make sense to heat a single house geothermally; the smallest heating load to justify such an investment would be a cluster of houses, an apartment block, an office complex, or a school. The heating load must be very close to the heat source. If the distance exceeded 10 km, or so, the cost of heavily insulated pipes in which to transport warm water would, in most places, make the project prohibitively expensive.

A water temperature of 50°C is the minimum usually required for geothermal heating — but not everywhere. Hot-spring waters at only 7°C, the lowest temperature of any of the world's practical applications of geothermal energy, keep Whitehorse's water supply from freezing; and by doing a job which formerly required burning oil, the springs save the town at least a million dollars every year.

In various reports on the economics of geothermal heating published during the 1970's, France, Hungary and Italy claim that geothermal energy costs about 20 per cent less than energy from alternative sources such as oil or coal. Iceland, which must import all its fuel, estimates the cost of geothermal heating to be at least 50 per cent less than that of the alternatives. In Canada it is not yet economical. Natural gas now heats Prairie homes for less than it would cost to pump warm water up from sedimentary rocks. However, if Canadians had to pay the world price for natural gas, rather than the subsidized domestic price, geothermal heating would be more competitive.

Geothermal Electricity

In volcanic rock, drilling is even more expensive than in soft sedimentary rock; moreover, a lot of drilling is required to map out a steam or hot-water reservoir. As well, the cost of pipework, turbines and generators, of all the hardware needed at a power plant, is by no means negligible compared to drilling costs. But despite the large investment required, so much heat can be concentrated in these rare reservoirs that converting it into electric power is, in fact, profitable. This is certainly true at The Geysers: the cost of each unit of electrical power fed by this plant into the power grid of northern California is about half the cost of a unit of power generated at a coal-fired station, and two-thirds the cost of a unit of power from a nuclear plant.

The conditions required for a geothermal resource to be economically exploitable for power generation are stringent. The resource must be located reasonably close to a major market for electricity. Superheated water, at least 180°C in temperature, or steam, must be present, and there must be a lot of it. Typically the drilling, hardware and operational costs are such that a plant which produces at least 100 MW of power must be built if the unit cost of power is to be competitive. Compared to the minimum size of a cost-effective nuclear or hydro power plant, however, this is small. One of the advantages of geothermal energy, in fact, is that economies of scale do not demand large plants; relatively small, and hence relatively inexpensive, plants can be built, and expanded in small blocks of power as knowledge of the geothermal field develops.

Canadian Projects

Who will own geothermal resources? Can an underground reservoir be claimed as mines are claimed, or traded like land? At present there are no satisfactory answers to such questions in Canada, where, legally at any rate, geothermal energy has a very tenuous existence.

This is not surprising; as it has not yet been exploited here the questions have not yet been asked. British Columbia, however, which may be the first province to harness geothermal power in Canada, has prepared clear legal rules governing its exploitation.

Canada is a newcomer to geothermal energy; it was not until the early 1970's that the search for our geothermal resources began. The federal government has played a major role in this search. Under the terms of the government's energy research and development program, the National Research Council has the task of co-ordinating work on renewable sources of energy. Its responsibilities in the area of geothermal energy are purely administrative. The Department of Energy, Mines and Resources, and in particular its Earth Physics Branch and the Geological Survey of Canada, has planned and executes the program of geothermal exploration and development. At the time of writing, 1982, the annual federal expenditure on geothermal energy has risen to around $750,000.

Geothermal explorers have walked, driven and flown over much of Canada's immensely varied terrain. From the volcanic rocks of the West, where they started by surveying hundreds of hot springs, they have gradually extended their search eastward across the sedimentary basin of the Prairies and on to the granites of the Maritimes. They have sifted through a mass of data, narrowing the focus of their search, and so far, have picked two geothermal resources from which energy may soon be produced: Mount Meager, in British Columbia, a potential source of geothermal power; and the University of Regina in Saskatchewan, a potential source of geothermal heat.

Drilling a production well under Mount Meager.

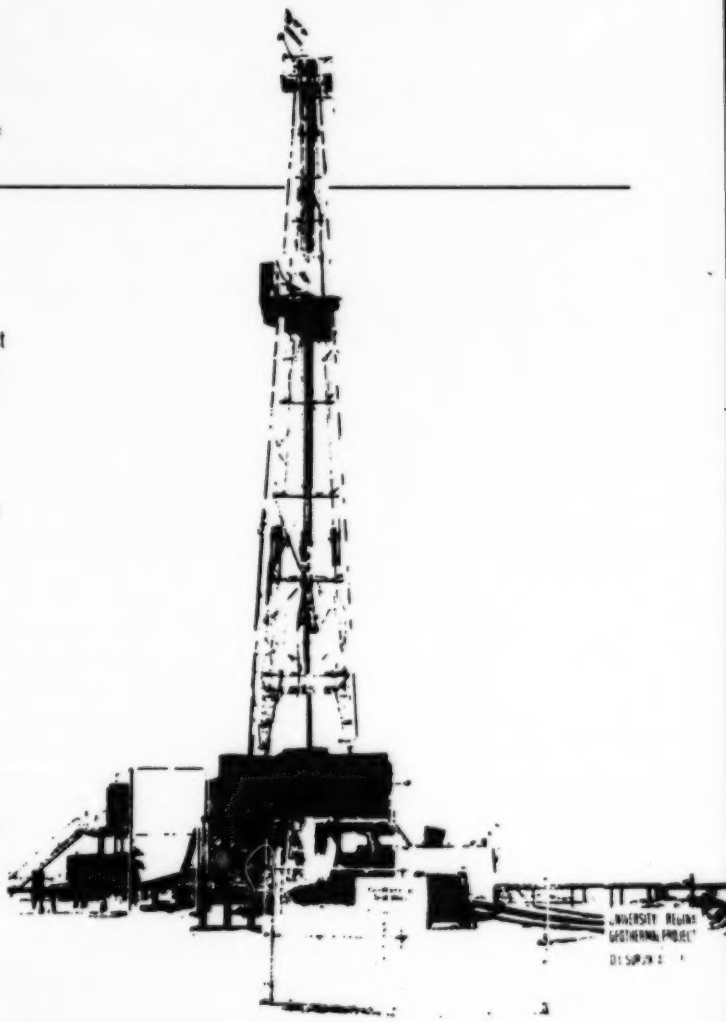
Mount Meager

A dormant volcano, with promising evidence in its hot springs of underground heat, and a location near the major energy market of Vancouver, makes a good geothermal prospect. After the selection of Mount Meager, a detailed investigation of the site was undertaken, in which the federal government researchers were joined by the provincial utility, B.C. Hydro, and several private consultant firms. Unravelling Mount Meager's geology was not easy; the vent from which it erupted has migrated some 10 km during its tumultuously active life, leaving the geologists with a fractured and buried confusion of rock. By means of seismic and electrical surveys however, two sites were pinpointed — one to the north of the mountain complex, the other to the south — under which pockets of steam were most likely to occur.

For geophysicists to take their measurements and plot them on their charts, a crew must first blaze and clear straight paths through the bush. In 1974 four men were cutting lines at the foot of Mount Meager. They had arranged to camp on a sandbar in a river when they were finished, and there they were to be picked up by a helicopter. But when the helicopter flew in, the pilot could find no trace of either crew or rendez-vous point. The valleys below Mount Meager are filled with gravel and sediments eroded from the mountain, for its rocks are crumbly. All that the pilot saw were signs of a fresh mud slide under which the lost line-cutters, camp and sandbar had all been buried.

In 1980, a B.C. Hydro drill crew, pushing close to the limits of what can be done with a light drill rig, measured a temperature of 202°C in a hole 367 m deep just south of Mount Meager. The rock cores brought up from this hole showed signs of having been chemically altered by hot water. On the basis of this evidence, geologists concluded that the drill was about to puncture the cap rock sealing an underground reservoir of superheated water, or possibly steam. They decided to go no deeper, but to return in the summer of 1981 with a heavier rig — one capable of handling a blowout of steam and boiling water.

To date, B.C. Hydro has drilled three 3000 m wells and has measured temperatures as high as 280°C but has not yet encountered a major steam producing zone. One of the purposes of this project is to find out



Drilling an experimental geothermal well into the sedimentary rocks beneath the University of Regina in Saskatchewan.

how much geothermal power costs in Canada. B.C. Hydro estimates that the capital investment in power from Mount Meager would probably be about a dollar per installed watt. While this is more than the investment for a new hydroelectric generating station, it is less than that for a nuclear or fossil-fuel power plant.

Federal geologists have now moved on to explore other geothermal prospects in the West. At Mount Cayley, a volcanic neighbor of Mount Meager's, they have measured temperatures which increase with depth at the rate of 94 °C/km, almost four times higher than the world average. They have also found unusually hot, though dry, rock in the interior of British Columbia and are exploring the province's small sedimentary basins. But their major interest, and the major geothermal potential in the West, is the electrical power which may be generated from steam or hot-water reservoirs. Dr. Alan Jessop of Energy, Mines and Resources Canada estimates that 1 500 MW of geothermal power could be generated in this volcanic zone by the year 2020. This would be a small, but valuable, contribution to Canada's energy supply.

Regina

A pioneering demonstration of geothermal heating has begun in Saskatchewan, at the University of Regina. Records from oil exploration indicated that within a layer of sedimentary rock under the city, there was scalding hot water at a temperature of 72°C. The university's Energy Research Unit became interested in the idea of tapping this reservoir to heat space and water inside a proposed new university sports building. In January 1979, with the help of federal (and some provincial) funds, an oil-drilling crew drilled to a depth of 2215 m on university land. Tests carried out on this well gave encouraging results, with one exception: the water was not as warm as expected. For some as yet unexplained reason, its temperature is only 63°C, less by ten degrees than water at the bottom of nearby wells of the same depth. This result is disappointing, but it has not ended the project. Though only 75 per cent of the heat energy initially expected is in fact available, this reduced quantity is still adequate for the heating load, about 3 MW. If the project continues, a second well will be drilled for returning cooled water to the ground.

The Regina researchers expect that it will take 40 years from the time the sports building is completed and geothermal heating commences before temperatures underground drop below useful values. They also expect that it will then take 400 years for the slow, steady flow of heat through the Earth to return the reservoir to its present temperature.

A modest beginning. But Dr. Jessop estimates that by the year 2050 approximately a quarter of all the people who live in towns in the Prairies with a population greater than 10 000 will enjoy the benefits of heat from geothermal energy. In the long run it is the warm water in sedimentary rocks which is likely to be our most significant geothermal resource.

Sources of Information

Organizations

British Columbia Hydro and Power Authority
970 Burrard Street, 19th floor
Vancouver, B.C. V6Z 1Y3
Publishes bulletins and has prepared a film on the Meager Creek project.

Bureau de recherches géologiques et minières
Avenue de Concyr
B.P. 6009 45060 Orléans
France
Publishes information on the use of geothermal energy in France.

Energy, Mines and Resources Canada
588 Booth Street
Ottawa, Ontario K1A 0E4
Geos, a bilingual quarterly magazine concerned with the Earth's resources, is distributed free on request. The Earth Physics Branch has published a series of technical papers on geothermal energy, and maintains a large collection of geothermal literature in its library.

National Research Council Canada
Montreal Road
Ottawa, Ontario K1A 0R6
The Energy Library of the Canada Institute for Scientific and Technical Information makes reports on geothermal energy and many other documents, available through interlibrary loans. The Public Information Branch publishes, and distributes without charge, booklets and the bilingual magazine Science Dimension.

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia U.S.A. 22161
A good source of information on, among other subjects, geothermal developments in the U.S.A. and other countries.

Pacific Gas and Electric Company
77 Beale Street, Room 1722
San Francisco, California
U.S.A. 94106
The News Bureau provides an information kit on The Geysers

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New York, 1978, 357 pp.
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P.O. Box 4869, Station E
Ottawa, Ontario, K1S 5B4
A monthly newspaper covering developments in all renewable energy technologies.

Geothermal Hotline
California Division of Oil and Gas
1416 Ninth Street, Room 1310
Sacramento, California
U.S.A. 95814
A free biannual published by the State of California.

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318 Cherrywood Street
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Science et Vie, mars 1979, 12 pp.

Weaver, Kenneth F
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National Geographic, October 1977, 14 pp.